System F6 Technology Package

Paul Eremenko
Program Manager
Tactical Technology Office

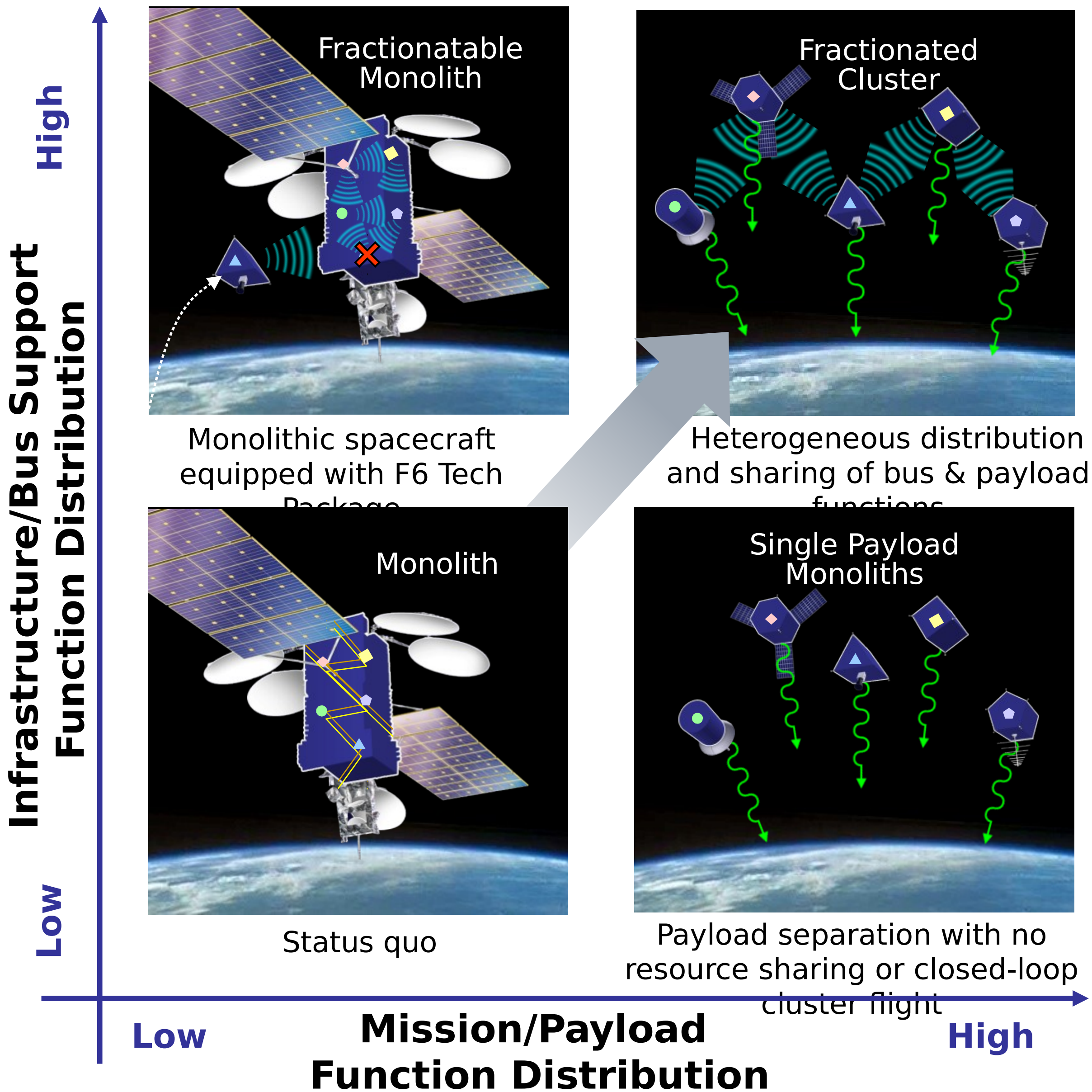
Proposers' Day Briefing

22 November 2011

Important Notes

- This briefing is based on the DRAFT solicitation (BAA)
  - https://www.fbo.gov/spg/ODA/DARPA/CMO/DARPA-SN-12-14/listing.html
- The text of the final solicitation will supersede anything briefed here
- Your comments and questions are important to improving the final BAA
  - Ask them in the Q&A session following this briefing
  - E-mail them to DARPA-SN-12-14@darpa.mil
- Two significant changes from draft BAA:
  - Error on p. 2 originally indicated a single award; multiple awards are anticipated
  - Timing of IDIQ award for flight unit development likely to move from initial development contract award to option period award
- There is also an F6 demo bus request for information (RFI)

Fractionated Space Architectures



Enablers of Fractionated Space Architectures

Cluster maintenance
Rapid cluster maneuvering
Relative navigation
Wireless networking
Real-time resource sharing
Multi-level security

24/7 LEO-ground connectivity

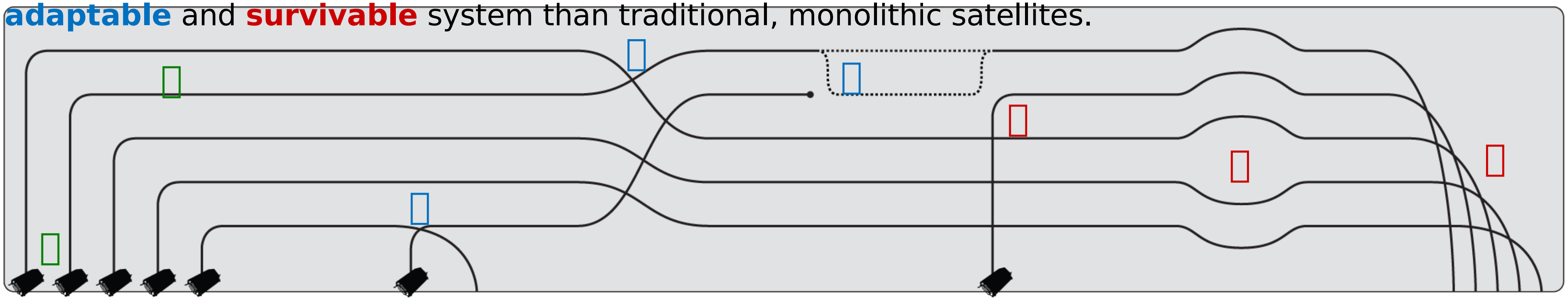
Open F6 Developer's Kit
Low cost F6 Tech Package

Adaptability Metrics
Design-for-Adaptability Tools

Military Utility of Fractionated Architectures

Fractionated System

F6 combines the strategies of distribution, modularization, and servicing into a single architecture, creating *virtual spacecraft* made up of free-flying, wirelessly networked elements. In addition to diversifying cost, schedule, and performance **risk**, this approach provides a more **responsive**, **adaptable** and **survivable** system than traditional, monolithic satellites.

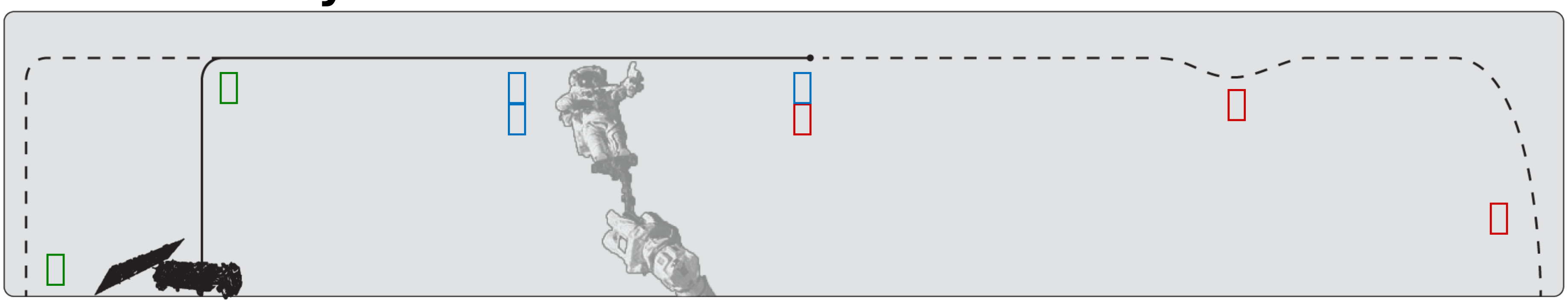


- Incremental deployment
- Utility accrues before all pieces on orbit

- Component upgrade/replacement possible
- Reconfigure for different missions
- Cluster-level redundancy

- Replace failed components
- Scatter to avoid attack or debris
- Graceful degradation

Monolithic System



- Single component can delay launch
- No utility until entire system is launched

- Upgrades rarely feasible
- Capabilities strictly set
- No system-level redundancy

- Failure of any part may prove catastrophic
- Larger target is more vulnerable
- Capability ends abruptly

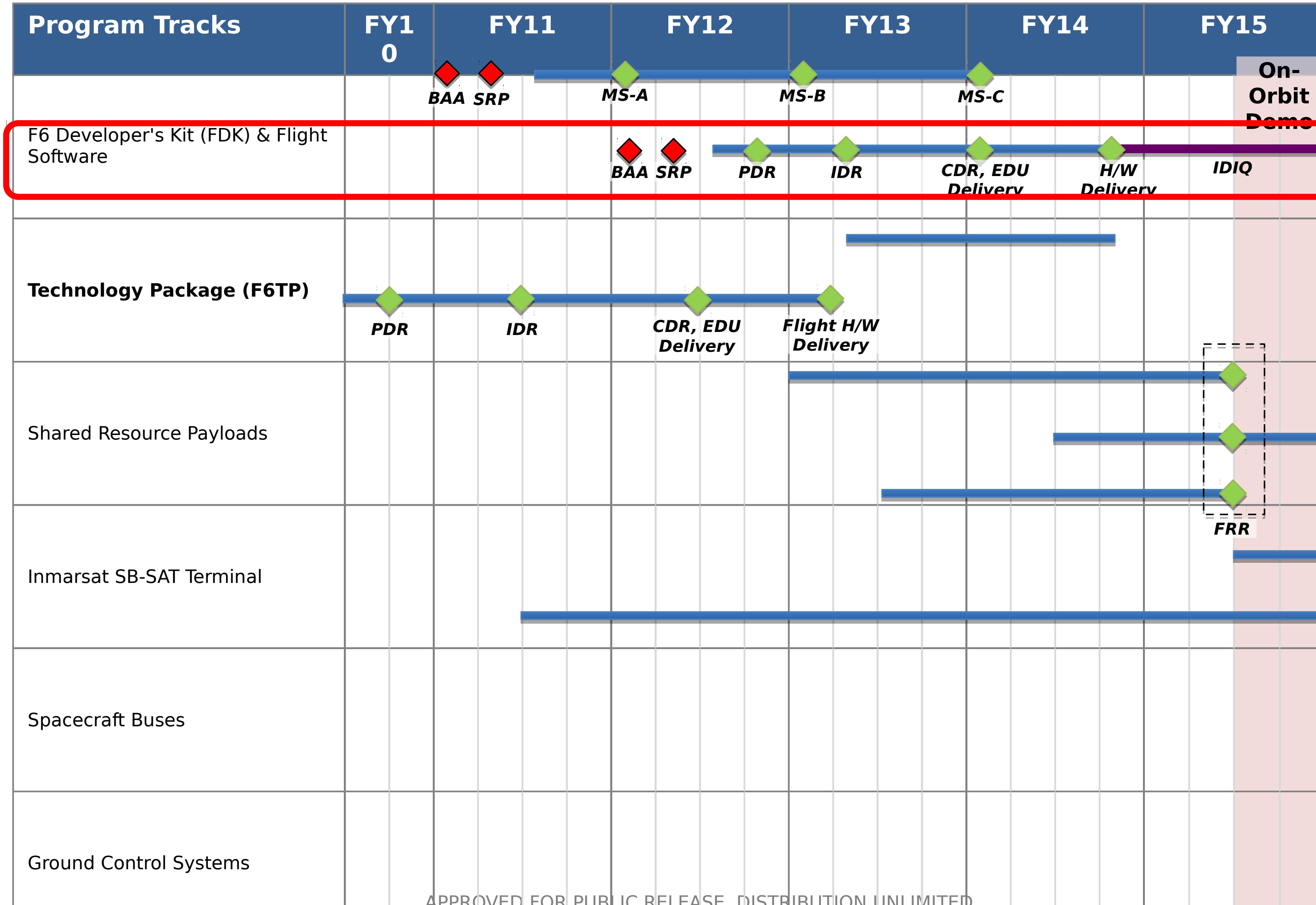
Key Program Artifacts

- **On-Orbit Demo**—demonstrate universal attributes of fractionated architectures
  - Launch in 2015, 6-month duration, low-earth orbit (LEO)
  - Mission agnostic beyond demonstration of key fractionation capabilities
  - F6 payloads, spacecraft bus procured separately at later date

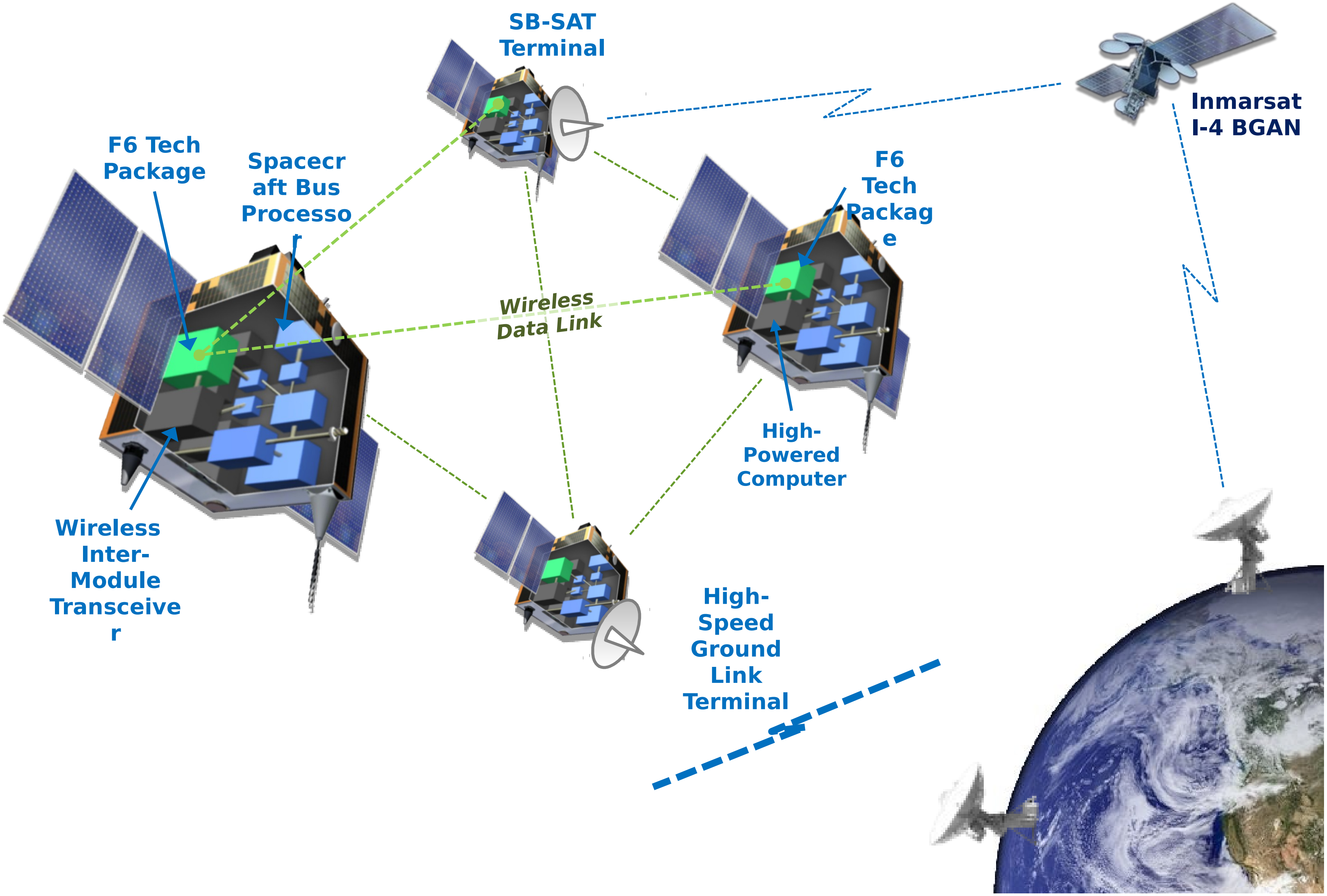
- **F6 Developer's Kit (FDK)**—everything needed for an independent third party to develop a module that can fully participate in a fractionated cluster
  - Interface standards, network protocols, software, behaviors/rules
  - Freely distributed under an open source license, freely exportable
  - Solicited previously under FDK BAA (DARPA BAA-11-01)

- **F6 Technology Package (F6TP)**—low cost, commercialized physical instantiation of the FDK that enables a spacecraft bus to become a fractionated cluster module
  - Executes protocol stack, middleware, cluster flight software
  - Interfaces to wireless inter-module transceiver, F6 payloads, and spacecraft bus
  - Multiple sources, capable of supporting multiple spacecraft bus types

Program Structure and Schedule

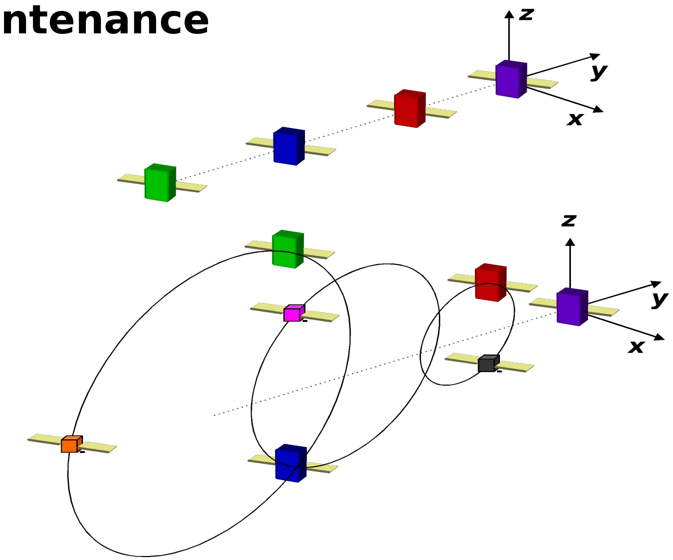


Notional System F6 On-Orbit Demo

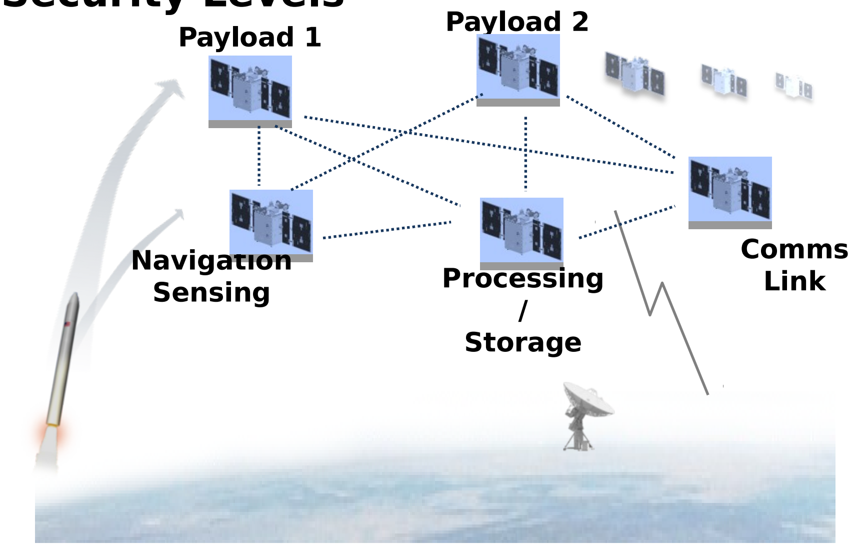


Key Capabilities for 2015 On-Orbit Demonstration

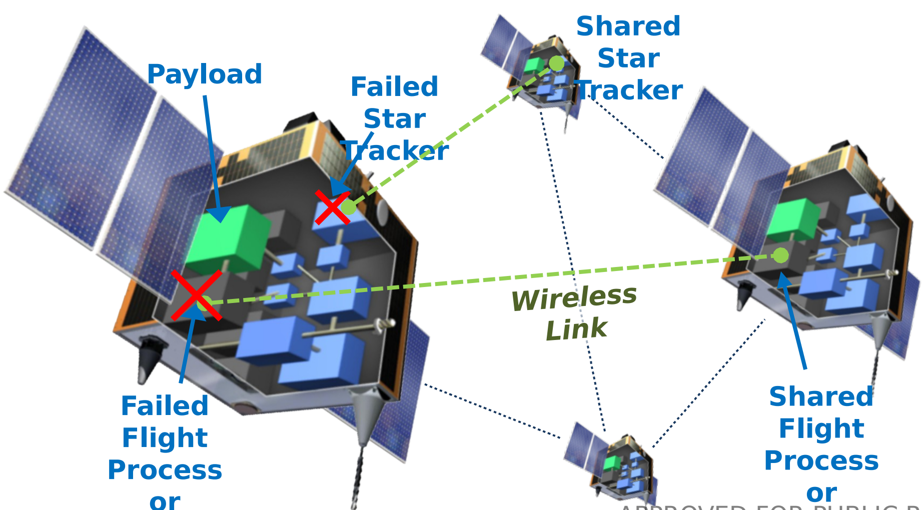
Demo 1: Long-Duration Cluster/Network Maintenance



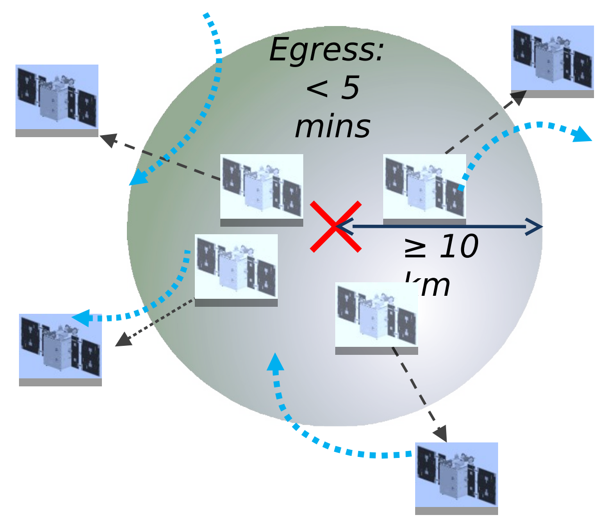
Demo 2: Resource Sharing at Multiple Security Levels



o 3: Cluster-Level Fault Tolerance



Demo 4: Defensive Scatter and Re-Gather



FDK Technical Areas*

OSI Model

Layer 7
(Application)

Layer 6
(Presentation)

(Session)

Flight
cal Area 4)

Information Architecture
(BAA Technical Area 3)

Wireless Inter-Module Communications
(BAA Technical Area 2)

* Aligned to prior System F6 FDK BAA issued in Fall 2010.

FDK Technical Area Two

Wireless Inter-Module Communications

- Aeronix and Southwest Research Institute

- Scope
  - Low data rate radios:
    - S-Band, mesh topology, up to 13.5Mbps
    - Ka-Band, mesh topology, up to 8.3Mbps
  - High data rate radio:
    - V-Band, point-to-point, up to 1Gbps per link

- Deliverables
  - FDK inputs: Layer 1, 2* protocols, software, reference implementations
  - Full terrestrial prototype test FDK
  - Four complete flight-ready units

* Layer numbers refer to the OSI Reference Model

FDK Technical Area Three

Information Architecture

- Vanderbilt University

- Scope
  - Layers 3 through 7 network protocols for space and terrestrial network
  - Distributed resource sharing across multiple security domains
  - Real-time fault tolerance, i.e., network and resource reconfiguration to maintain safety-critical functions and gracefully degrade mission capability

- Deliverables
  - FDK Inputs: Operating system, Layers 3-7 protocols, middleware, multi-level security architecture
  - Fully verified and validated flight software

Cluster Flight

- Emergent Space Technologies

- Scope
  - Multi-body cluster flight algorithms and behaviors
  - Passively safe relative orbit configurations
  - Long-duration semi-autonomous cluster ops
  - Autonomous rapid maneuvering capability—defensive scatter (20 km, 5 mins)

- Deliverables
  - FDK Inputs: Algorithms, behaviors/rules, reference implementation
  - Fully verified and validated flight software

FDK Technical Area One

Design Tools for Adaptable Systems

- Jet Propulsion Laboratory (JPL) and Stevens Institute of Technology

- Scope
  - When does the business case for fractionated architectures close?
  - When it does close, how should a system be optimally fractionated?
  - Quantitative measure of adaptability
  - Quantitative trade-offs between adaptability and traditional system attributes (size, weight, power, cost, performance, etc.)

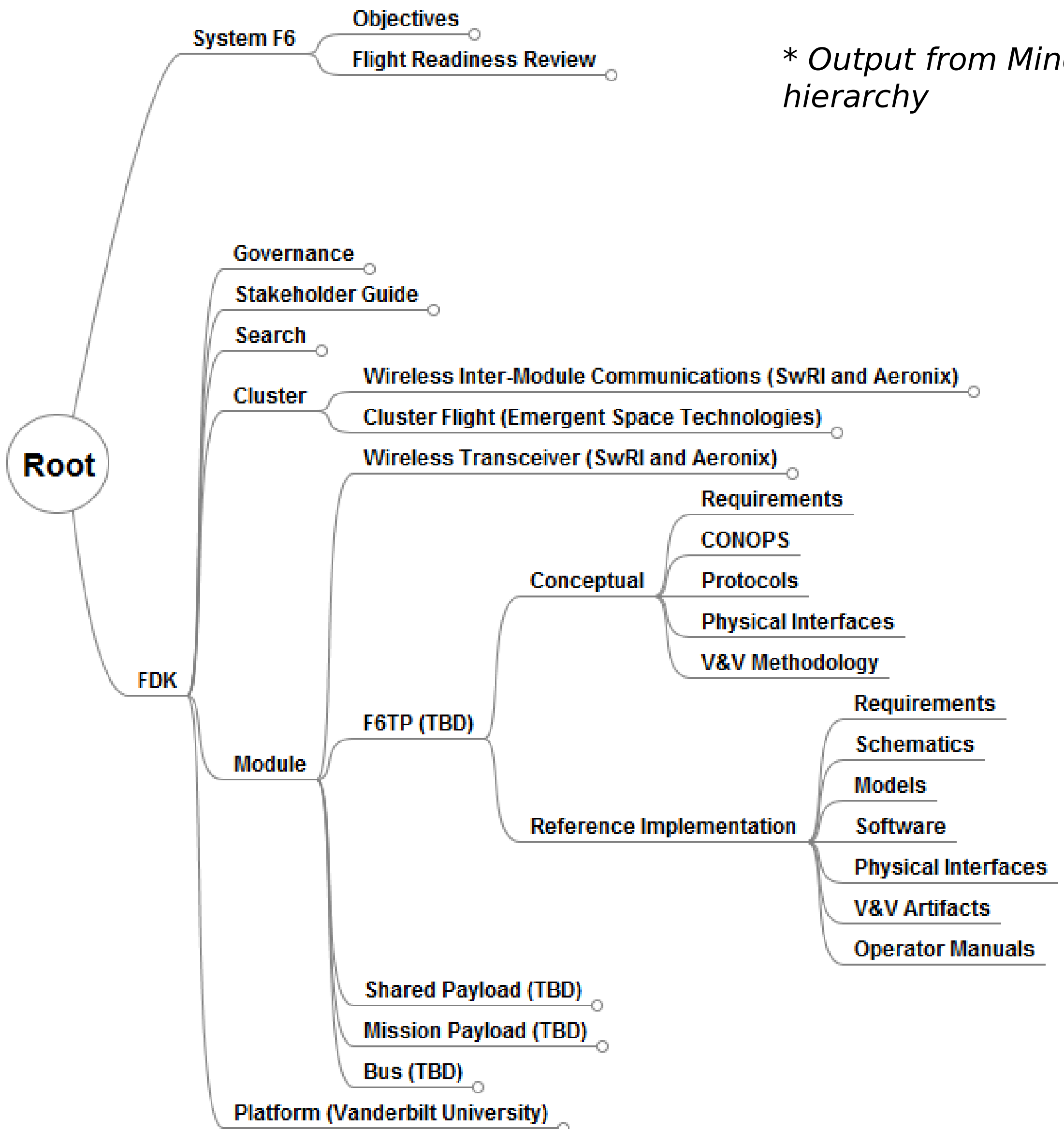
- Deliverables
  - Fully-functional, validated, polished, well-documented, user-friendly tool
  - Potential to inform F6TP business case and design choices

FDK Structure

- The FDK is structured as a hierarchy of holons (model-based components)
  - Organized as an electronic entity in a subversion repository
  - Configuration managed, version-controlled, and distributed electronically
  - Each holon is the responsibility of a single organization
  - Each holon has attributes (e.g., unique name, version, description)
  - The relationship attribute is used to define relationships between holons
  - A conceptual definition holon defines a generic instance
  - A reference implementation holon defines a specific instantiation of a conceptual definition holon

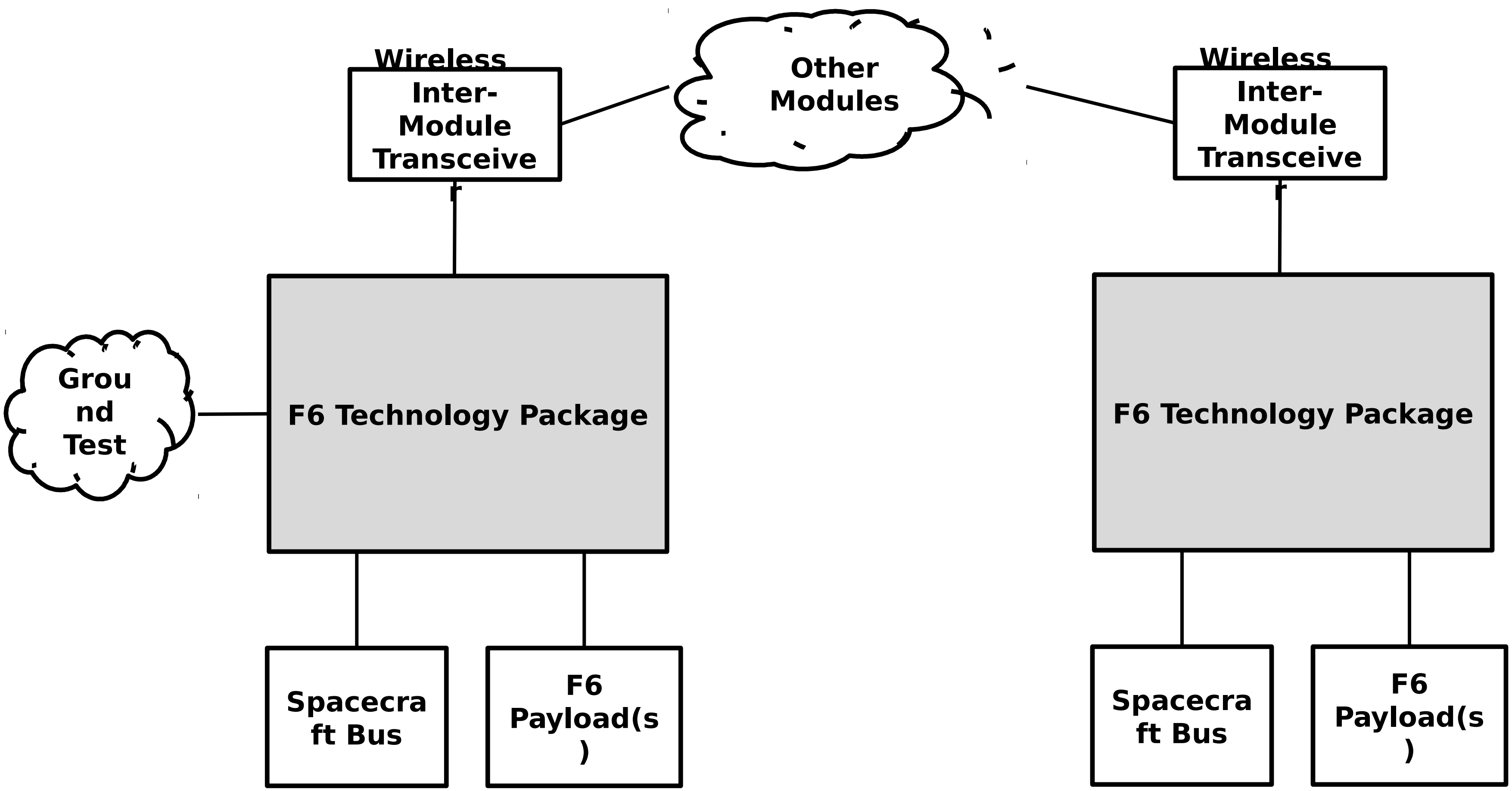
- A draft FDK is included in the Appendix of the BAA

Current FDK Holarchy (Hierarchy)



** Output from Mindmap view of FDK hierarchy*

F6 Technology Package (F6TP)



F6TP BAA Philosophy

- Minimal constraints (BAA functional objectives) to enable demo mission

- Goal is to identify a “sweet spot” in the F6TP design trade space to maximize its commercialization potential in various market segments
  - E.g. low-cost nanosatellite model, high-powered large satellite model
  - <u>NOT</u> looking simply for the lowest-cost or highest-performance F6TP design

- Must consider manufacturability and production unit cost—proposals must include contract option for government to purchase production units at firm pricing for up to 5 years
  - Structure of IDIQ CLIN will most likely look different in final BAA

- Each proposal should define a <u>single</u> F6TP point design

F6TP Objectives

- Four groups of BAA objectives corresponding to minimal constraints:
  - Mission objectives
  - Functional objectives
  - Interface objectives
  - Manufacturing and commercialization objectives

- A summary is provided in the following slides; see draft BAA for complete definitions and additional clarification text

F6TP Award Structure

- 15-month base development period
  - PDR, CDR, and breadboard prototype demonstrations
  - Delivery of engineering development unit (EDU)

- Contract option with two additional contract line items (CLIN)
  - Option Period CLIN
    - Additional 12-month development period
    - Completed engineering qualification unit (EQU)
    - Qualification tests completed
  - IDIQ (indefinite delivery/indefinite quantity) CLIN
    - Must remain open for 5 years subsequent to 27-month development period
    - Facilitate purchase of flight-qualified production units by government agencies
    - DARPA will purchase at least one unit from each awardee
    - Unit pricing may be constant or variable with order lot size/delivery timeline
    - Timing of submission of IDIQ proposal is likely to change in the final version of the BAA from initial proposal submission to end of base period

Intellectual Property and Data Handling

- IP rights
  - The government desires at least Government Purpose Rights (GPR) to all deliverables
  - Government prepared to accept lesser rights to clearly-identified, widely-available, unmodified commercial hardware and software, with their commercial availability and license grant terms described in proposal

- International Traffic in Arms Regulations (ITAR)
  - Must comply with ITAR and other export control statutes
  - FDK is not subject to export control restrictions as it is public domain information

- Pre-publication restrictions
  - Program is funded with “6.3” dollars—requiring pre-publication review
  - Exceptions (via “6.2” funding swaps) *may* be possible on a case-by-case basis

Proposal Info

- Proposals intended to be concise but technically specific
  - Single integrated technical and cost volume
  - No page limits but conciseness and clarity of prose matters
  - Procurement contract (CPFF, FFP-Milestone Payable), other transaction agreement (OTA), or Space Act agreement (SAA) instruments possible
  - Contracted by DARPA/CMO or NASA Ames (TBD)
- Proposal evaluation criteria
  - Commercialization potential
  - Technical merit
  - Alignment with DARPA vision
  - Credibility of offeror's team
  - Cost realism
- Opportunity for written Q&A during proposal preparation period
  - Questions directed to the BAA mailbox specified in the final BAA
  - Comments on the draft BAA should be directed to: **DARPA-SN-12-14@darpa.mil**

Notional Timeline

- Draft BAA released—18 November 2011
- BAA comments due—30 November 2011
- Final BAA released—5 December 2011 (est.)
- BAA questions due—6 January 2012 (est.)
- BAA question responses posted—10 January 2012 (est.)
- Proposals due—6 February 2012 (est.)
- Selection Notification—29 February 2012 (est.)
- Contract Award—late May/early June 2012 (est.)

F6TP Detailed Objectives

Dawn McIntosh
System F6 Chief Engineer
NASA Ames Research Center

Proposers' Day Briefing

22 November 2011

Mission Objectives (1)

- MO1. Size: The F6TP installed volume should be less than 3,000 cm^3.

- MO2. Mass: The F6TP should have a packaged installed mass of 5 kg or lower.

- MO3. Power: Offerors should clearly define power consumption values and associated assumptions including:
  - MO3a. Peak: The F6TP should have a peak power consumption not greater than 20 W.
  - MO3b. Average: The F6TP should have an average power consumption not greater than 10 W.

Mission Objectives (2)

- MO4. Reliability: The F6TP should be able to survive launch and function for the duration of the 6-month on-orbit demonstration mission with a reasonable probability. The risk of quality- and workmanship-related failures should be minimized through detailed plans for:
  - MO4a. EQU: For the engineering qualification unit (EQU), perform qualification-level testing for worst case launch/space environment.
  - MO4b. FU: For flight units (FU), perform integrated spacecraft-level testing for worst case launch/space environment and a minimum of 200 hours of thermal vacuum testing time at the expected operating temperature range

- MO5. Launch Environment: The F6TP should be able to withstand launch loads, and vibration and acoustic environments consistent with a Minotaur 1, Minotaur 4, Taurus, Taurus 2, EELV Secondary Payload Adapter (ESPA), Falcon 9, and Pegasus launch vehicles.

Mission Objectives (3)

- MO6. Space Environment: The F6TP should be qualified to operate in radiation environments expected of any orbit in LEO. This objective is not intended to limit solutions to already space-qualified or radiation-hardened technologies only. Innovative approaches to this objective are encouraged, including analytical and experimental assessments of terrestrial technologies and components.
  - MO6a. Total Dose: The F6TP should be qualified to a minimum total radiation dose of 15 kRads (Si).
  - MO6b. SEU: The F6TP should be qualified to a minimum Single Event Upset (SEU) threshold of 20 MeV/mg/cm^2.
  - MO6c. Latch-Up: The F6TP should be qualified to a minimum Single Event Latch-Up threshold of 50 MeV/Mg/cm^2.
  - MO6d. Temperature: The F6TP should be able to operate within a temperature range of -40 to +85 degrees Celsius.

- MO7. Materials Safety & Compatibility: The F6TP should not contain materials that are known sources of contaminates or hazards in the space environment.

Functional Objectives (1)

- FO1. <u>Computational Capabilities:</u> The following baseline objectives are derived based on best available estimates.
  - FO1a. The F6TP should provide at least 250 MIPS of computational capability.
  - FO1b. The F6TP should provide at least 512 megabytes of volatile memory.
  - FO1c. The F6TP should provide at least 4 gigabytes of non-volatile memory.
  - FO1d. The F6TP should provide additional computational and memory capacity required for interfacing with the wireless inter-module transceiver
  - FO1e. The F6TP should provide at least one processor core supporting 32-bit (or larger) fixed-point and floating-point operations.
  - FO1f. The F6TP should provide a memory management unit supporting individual page protection for pages as small as 4,096 bytes.
  - FO1g. The F6TP should provide at least two instruction execution modes, one privileged and the other not.

Functional Objectives (2)

- FO2. Resets: The F6TP should respond to hard resets, soft resets, and cold boot modes in conjunction with software image selection.
  - FO2a. Authenticity: Software image execution should occur only if the image is validated by secure hash check.
  - FO2b. Anti-Tamper: The F6TP should provide a capability for assuring that software images in the F6TP are valid and have not been tampered with.

- FO3. Timekeeping: The F6TP should provide high-resolution timing capabilities to support interrupts and cluster-synchronization.
  - FO3a. Timers: The F6TP should provide at least three high-resolution timers with a granularity of no less than 10 nanoseconds.
  - FO3b. Counter: The F6TP should provide a high-resolution real-time counter that provides a monotonically increasing count of constant-duration timer ticks (with resolution no less than 10 nanoseconds) since a reset. This counter should have the capacity to count, without overflow, for at least 30 years.

Functional Objectives (3)

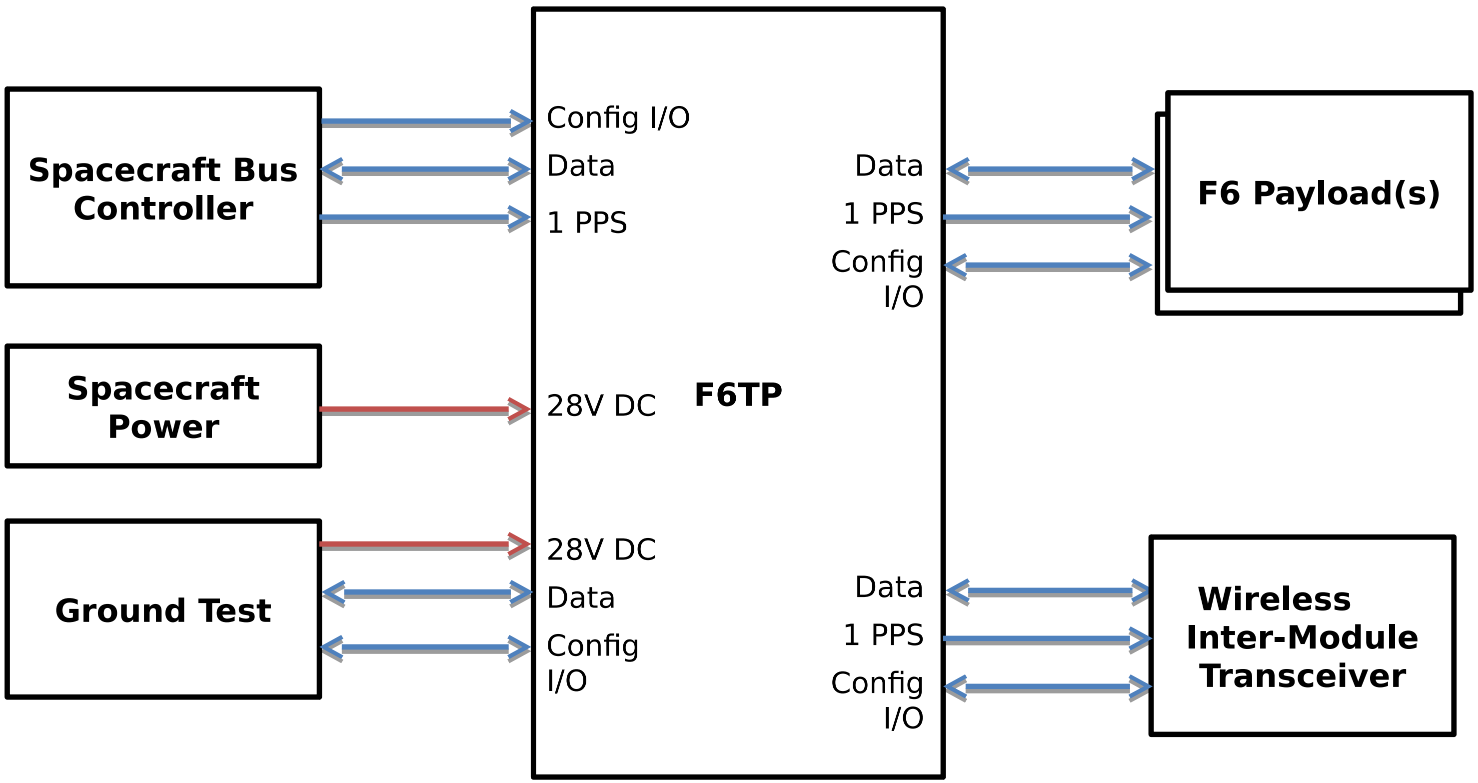
- FO4. <u>OS Support:</u> The F6TP should be capable of efficiently and natively supporting traditional operating systems (OS) such as Linux and VxWorks and microkernel and/or virtual machine monitor systems, without requiring workarounds that materially affect operating system performance.

- FO5. <u>FDIR:</u> The F6TP should exhibit fault detection, isolation, and response (FDIR) behaviors.
  - FO5a. The F6TP should conduct self-tests under software control, to verify correct hardware operation.
  - FO5b. The F6TP should detect and respond to hardware faults and Single Event Upsets.

Functional Objectives (4)

- FO6. IA Support: The F6TP should include support for a set of core functions that enable information assurance (IA) capabilities.
  - FO6a. Cryptographic Acceleration: The F6TP should provide cryptographic acceleration mechanisms for NSA Suite B symmetric cryptography and that facilitate the common symmetric cryptographic operations expected to be used for protection of communication and storage.
  - FO6b. Random Numbers: The F6TP should include a hardware-based mechanism for generating random numbers.
  - FO6c. Secure Storage: The F6TP should provide a secure storage mechanism for holding at least 32,768 bytes of cryptographic variables and initialization data.

Interface Objectives (1)



Interface Objectives (2)

- IO1. Wireless Inter-Module Transceiver Interface: The F6TP should interface with a wireless inter-module transceiver.
  - IO1a. LDR: The F6TP should be able to support management of data delivered through the low-data rate (LDR) mode of the wireless inter-module transceiver, which may operate up to 100 megabits/second. Offerors should propose a set of configurable data bus interfaces and device drivers between the F6TP and wireless inter-module transceiver, to include SpaceWire and Controller-Area Network (CAN) at a minimum.
  - IO1b. HDR: Optionally, the F6TP should be able to support the above data transmission and storage objectives for the high-data rate (HDR) mode, assuming a minimum wireless inter-module link rate of 1 gigabit/second. Offerors should propose a set of configurable data bus interfaces and device drivers between the F6TP and wireless transceiver, to include Gigabit Ethernet (GbE) and Low-Voltage Differential Signaling (LVDS) at a minimum.

Interface Objectives (3)

- IO2. Payload Interface: The F6TP should concurrently interface with at least two external spacecraft payload devices such as sensors, communications transponders, or other data links (such as the Inmarsat SB-SAT). Offerors should propose a set of configurable data bus interfaces and device drivers, to include SpaceWire and CAN at a minimum.

- IO3. Spacecraft Data Bus Interface: The F6TP should interface with a spacecraft bus controller via RS-422, SpaceWire, or CAN data bus interface to exchange attitude, timing, navigation, commands, telemetry, and acknowledgements.

- IO4. Spacecraft Power Bus Interface: The F6TP should interface with the spacecraft bus power distribution controller. The F6TP should nominally operate at the standard spacecraft bus voltage of 28V +/- 6V DC.

Interface Objectives (4)

- IO5. <u>Ground Test Interface:</u> The F6TP should interface with external systems during test and pre-launch configurations.

- IO6. <u>General I/O:</u> The F6TP should have at least 16 single-bit digital input/output (I/O) signal lines for resets and other functions.

- IO7. <u>Timing:</u> The F6TP should provide 1 pulse-per-second (PPS) output signals accurate to one part per million that can be distributed to peripherals for timing synchronization.

Manufacturing and Commercialization Objectives (1)

- CO1. Manufacturability: The F6TP should be designed with manufacturability considerations and leveraging commercial best practices to:
  - CO1a. Efficiency: Maximize production efficiency and leverage production learning even at low volumes.
  - CO1b. Transit Time: Reduce product transit time through the manufacturing process, i.e., latency from order to delivery.
  - CO1c. Scalability: Enable efficient scaling from single volume production to a production rate of ~1,000 units per year.

Manufacturing and Commercialization Objectives (2)

- CO2. Commercialization: The F6TP design should be founded on a sound commercialization strategy that informs the performance, reliability, cost, and other design trade-offs in the offeror's proposal.
  - CO2a. Addressable Market: The offeror should have a qualitative and quantitative understanding of the target addressable market for their F6TP design.
  - CO2b. Means of Distribution: The offeror should employ appropriate and innovative means of reaching their target market for F6TPs.
  - CO2c. Policy Impediments: The offeror should understand and minimize the policy impediments to the widespread commercialization of the F6TP.
  - CO2d. Business Model: The offeror should have a clear, articulable, and substantiated business model that supports their F6TP design decisions.

- ~~CO3. Production Unit Cost: The offeror should provide firm pricing for the production of F6TP flight units (FUs).~~*

F6TP Milestones and Deliverables (1)

- Preliminary Design Review (Award + 4 months)
  - Complete architectural design, top-level system layout
  - Substantiation of all key design trades, estimates of performance and objectives compliance, specification of all interfaces and dependencies, risk analysis, test/verification plan
- Breadboard Unit Delivery & Demo (Award + 8 months)
  - Hardware instantiation of updated PDR design in representative hardware
  - Simulated with low-fidelity spacecraft and payload simulators at the interfaces
- Critical Design Review (Award + 12 months)
  - Documentation of complete detailed design
  - Complete released engineering drawings and models for the entire system
  - Detailed performance analysis with respect to all objectives, risk analysis, test/verification plan
- EDU Demo and End of Base Period (Award + 15 months)
  - Hardware instantiation of CDR design
  - Base period final technical and programmatic report and delivery of all program data, software, and items/articles
  - Technical manuscript summarizing key technical accomplishments

F6TP Milestones and Deliverables (2)

- Engineering Qualification Unit (EQU) Delivery (Award + 19 months)
  - Completed flight-unit for qualification tests
  - Environmental qualification including vibration, acoustics, thermal vacuum, and radiation testing
- End of Option Development Period (Award + 27 months)
  - Final technical and programmatic report and delivery of all program data, software, and items/articles
  - Technical manuscript summarizing key technical accomplishments
- First Flight-Unit Delivery (Award + 28 months)

Additional Periodic Deliverables

- Program-wide PI meetings
  - Held bi-monthly in a major metropolitan area with easy access by air
  - Principal forum for delivery of performer results
  - Attended by all F6 performers including other F6TP performers
- Monthly technical report
  - Delivered via Sharepoint and email
  - Shared with all F6 performers
- Monthly financial and hours report
  - Delivered via Sharepoint and email
  - Accessible by government team only
- Weekly informal teleconference of technical progress (30-45 minutes)
- Site visits
  - Informal visits and discussions with government team
  - 4-8 hours per visit, every 2 months

System F6 Program Integration

- F6TP performers are expected to collaborate with FDK performers to develop and demonstrate an integrated capability and solution

- Open sharing between all F6 performers is expected at program-wide PI meetings and collaboration forums including wiki and teleconferences

- NASA Ames F6 System Integration Lab (SIL) will provide common software repository, wiki, issue tracking tools, and infrastructure for integration demonstrations

- Performers are expected to work with government team to determine key tradeoffs that affect multiple program performers

System F6 Tech Package Draft BAA:

https://www.fbo.gov/spg/ODA/DARPA/CMO/DARPA-SN-12-14/listing.html

Direct Comments on Draft BAA to:

DARPA-SN-12-14@darpa.mil